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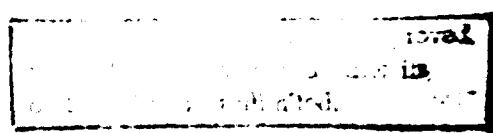
FALLOUT RADIATION EXPOSURE CONTROL
(AN INTRODUCTION)

by

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PREFACE

This paper is intended for use by postattack research contractors and other interested persons as a summary statement on the problems of radiation exposure control with emphasis on the period after people emerge from shelter. This paper is the first of its kind on the subject and, for this reason, certain background material is included. An effort is made to identify and discuss problems in simple and direct language, and to relate to operational situations. Loss of precision that results thereby is not likely to change the implications and conclusions in any important way. References listed at the end of the paper contain the up-to-date scientific information on this subject; also, footnotes are used in some cases to provide supplemental information.

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SUMMARY

As a result of weapons test programs in Nevada and the Pacific, and through extensive laboratory and theoretical studies, a great deal has been learned about the properties of fallout and ways to protect against it. However, experience has shown that many people misinterpret information on this subject. A broad grasp of authentic information about fallout seems to be lacking, partly because much of it is new, partly because it has been distorted in fiction, and partly, no doubt, because it is complicated subject matter and difficult to present clearly, especially to a non-technical audience.

The following is a list of points that seem to be misunderstood most often. They are discussed in some detail in the body of the report.

1. In dangerous concentration, radioactive fallout in a nuclear war would look and behave much like sand or dirt, and like them, it could be seen, felt, or tasted. Thus, the physical senses could be relied upon to determine whether or not a fallout hazard exists. Evaluation of the degree of hazard would require special instruments.
2. The over-riding danger from fallout is external exposure to gamma radiation. Inhalation presents little or no hazard and the danger due to eating or drinking contaminated food or water, in almost all cases, would be minor.

3. Beta radiation can cause skin damage if fallout material is allowed to remain for some time in contact with the skin. However, such damage (beta burns) would result only if the fallout were highly radioactive (only a few hours old). Beta burns would be easy to prevent simply by keeping the skin covered or brushing off material that came in contact with the skin. Therefore, the beta-burn problem is not considered very important.

4. Shelters provide the way to "save lives" threatened by fallout gamma radiation. Their's is the critical role during the very early time after fallout -- nominally up to about two weeks.

5. Decontamination does not "save lives" in the sense that shelters do. Its role is to shorten shelter stay-time and to allow earlier access and use of important facilities. After decontamination, a facility that would otherwise have been denied for months because of high radiation levels could be recovered and made operational within days to weeks after the attack.

6. The Protection Factor, (Pf), for a shelter defines the reduction in radiation level expected in the shelter compared to the radiation level in an unprotected location (assuming the same concentration of fallout). This does not mean the expected "in shelter" radiation level compared to the "outside" radiation level, since there would always be some protection outside -- from nearby buildings or features of the terrain. For

example, the ratio of the outside to inside radiation level for a Pf-100 shelter might be nearer 50 than 100.

7. Evacuation, decontamination, and/or part-time shelter use provide an adequate means for radiation exposure control after, and in many cases before, expiration of the nominal two-week shelter stay-time. Therefore, with proper planning and organization, the receipt of incapacitating exposures during the post-shelter period could be avoided.

BACKGROUND

It was not until the last few years that problems of post-shelter exposure control received much attention. Research on it has been limited primarily to a very few places including the Naval Radiological Defense Laboratory, the Army Nuclear Defense Laboratory, the Stanford Research Institute, the Civil Defense Project of the University of California, United Research Services, and the Research Triangle Institute. As in any new field of investigation, different approaches have been used and different nomenclature employed.

For this reason, certain of the important parameters and concepts that provide background for the consideration of post-shelter exposure control are summarized.

The Nature of Fallout

The origin of the term "fallout" is associated with the detonation of the first nuclear device, Shot Trinity, at Alamogordo, New Mexico, July 16, 1945. The material "falling out" of the mushroom cloud produced by the explosion was radioactive.

Definition

Fallout is defined in the handbook "The Effects of Nuclear Weapons" prepared by the Department of Defense and published by the Atomic Energy Commission, as follows:

"FALLOUT: The process or phenomenon of the fallback to the earth's surface of particles contaminated with radioactive material from the radioactive cloud. The term is also applied in a collective sense to the contaminated particulate matter itself. The early (or local) fallout is defined, somewhat arbitrarily, as those particles which reach the earth within 24 hours after a nuclear explosion. The delayed (or world-wide) fallout consists of the smaller particles which ascend into the upper troposphere and into the stratosphere and are carried by winds to all parts of the earth. The delayed fallout is brought back to earth, mainly by rain and snow, over extended periods ranging from months to years."

Through studies starting with Alamogordo and continuing during test series at the Nevada and the Pacific Proving Grounds -- aided by extensive laboratory and theoretical work -- much has been learned about the properties of fallout.

Creation and Distribution*

An explosion of any kind, detonated near the surface of the earth, causes material to be thrown up or drawn into a chimney of hot, rising gases and to be carried aloft. In a nuclear explosion, two important

* Much of this material is taken from Reference 2.

things happen: (1) radioactive elements, produced by the explosion and vaporized by heat, condense into or on the material sucked into the rising gases; and (2) for a surface burst, great amounts of the surface material rise thousands of feet into the air before the particles begin to fall back. This permits the winds to scatter radioactive particles over areas many times larger than the areas affected by the immediate blast and thermal effects of the bomb.

Soil is the major component of the fallout resulting from a nuclear detonation at or near the surface of land (this would include city-target locations). In detonations at or near the surface of the ocean, the major components are the sea-water residues and water. From an air burst not near the surface of the earth, the major fallout components are from the weapon or the warhead materials -- uranium, iron, and aluminum, in the form of oxides. Because the amount of these weapon materials is not large, it is vaporized in the explosion and condenses in the earth's atmosphere to form only very small fallout particles.

Fallout from the near-surface land burst, consisting of many particles larger than those produced by an air burst, descends rapidly to the earth and results in much higher deposition of radioactive material per unit area of surface than results from an air burst. Because of this large difference in the deposition characteristics of the fallout and the

corresponding radiological hazard, only the type of fallout characteristic of a land-surface burst is considered here. A large-yield detonation near the surface of the water in a shallow harbor, lake or river; or near-offshore along the ocean front would produce fallout having about the same characteristics as that from a land-surface burst.

The principle civil defense problem associated with fallout arises from the gamma radiation that is emitted by the fallout particles produced in land-surface detonations. Fallout from a large-yield, ground-burst nuclear weapon could result in dangerously high levels of gamma radiation up to hundreds of miles from the place of the detonation. This fallout would occur some time after the explosion that caused it since the dispersion of the fallout particles over the earth's surface depends on the wind speed and direction at various altitudes, and the time required by the various-sized particles to be brought back to earth by the force of gravity. For example, if the average wind speed were 25 miles per hour, and in the same direction at all altitudes traversed by the falling material, fallout would begin to arrive 100 miles downwind about 4 hours after the burst. No mathematical model presently available predicts very accurately how long fallout particles would continue to be deposited at any particular place, but it has been observed that usually the longer between the time of detonation and the time that fallout began to arrive,

the longer the deposition time. In the case considered above, fallout that began to come down at 4 hours after the burst that caused it might continue for another few hours.

Depending on the time of day and the condition of the atmosphere -- rain, fog, or haze -- the early fallout probably would be seen as it approached, much in the manner of a rain, snow, or dust storm.* If sufficient fallout were deposited to be very dangerous, anyone looking for it could see it either as it came down or as it accumulated on such surfaces as automobiles, sidewalks, streets, or window ledges. Fallout is not the invisible, gas-like substance pictured by many; it is made up of real, tangible particles that would be very difficult to ignore, especially if enough were around to be dangerous.

Because of the variations in weapon yields and winds and soil characteristics, no one can say exactly just how far away from a detonation serious levels of fallout would occur, but the danger area from a single explosion might cover several hundred miles downwind, a few miles upwind, and tens of miles crosswind. In a war where a number

* See definition on page 2, and Reference 2 for additional discussion.

"Early fallout" is of major concern to civil defense and the shelter and decontamination countermeasures are required because of it.

"World-wide fallout" would contribute primarily to the ingestion hazard which is far less serious than the external exposure hazard of the "early fallout."

of upwind detonations occurred, the pattern of fallout deposition would be more complicated, but fallout which does not arrive within the first 24 hours of the burst that produced it probably would not present a serious emergency problem to civil defense.

Properties of Fallout

Direct civil defense experience with protection of a population against fallout does not exist. The two nuclear bombs used during World War II in Japan were detonated at altitudes which maximized blast effects. Thus the weapons were air bursts and no early fallout was produced. No other nuclear weapons have been detonated over a city complex, so the basis for predicting the type of fallout that would be created by ground-bursting a weapon on a target city must be drawn from the tests in Nevada and the Pacific and from theoretical and laboratory studies. Extensive efforts have been devoted to such studies and a great deal is known about fallout's physical, chemical, and radiological properties.

Physical Properties of Fallout

In many respects, the most useful means for visualizing early fallout is to think of it simply as sand. Sand in the proper size range is considered to be physically so close an approximation to fallout that it

has been used extensively as a fallout simulant in decontamination studies. The fallout from test shots in the Pacific has been white since it consisted primarily of calcium oxides and carbonates from the coral islands. The Nevada fallout, composed primarily of alluvial soil, was generally darker. War-produced fallout, like weapon-test fallout, probably would be composed of a mixture of sharp-edged irregular particles and of spherical particles with smooth surfaces, and its color would be derived from the material over which the bomb that produced it was exploded -- probably in the brown-grey-black categories.

Having established a basis for visualizing fallout, the next question usually raised is: How much? In decontamination experiments at the Naval Radiological Defense Laboratory and the Army Nuclear Defense Laboratory, the amounts of simulant calculated to represent the mass of material typical of that expected in areas seriously contaminated by large-yield nuclear weapons generally are in the range of an ounce to a pound of material per square foot.* An asphalt street, after being contaminated to this extent using the beach-sand simulant, looked white rather than black. However, winds sweeping over the relatively smooth surfaces rather quickly redistributed the fallout against curbs, buildings, and other obstructions. Lawns, planted areas, and fields tended to trap and retain the particles.

* Calculations of mass associated with various fallout conditions based on the Miller Fallout Model are presented in Reference 3.

An understanding of the physical nature of fallout is useful in considering problems that depend primarily on the physical behavior of fallout. Fallout ingress into a shelter, or personnel and food contamination are examples.

Like the problem of sand in the cottage at the beach, some fallout may be tracked or otherwise infiltrate into a shelter, but it should not be hard to keep most of it out. If some fallout did get in a shelter it could easily be swept up and thrown out. In shelter utilization planning, the objective is to have people in shelters before fallout occurs. If the fallout-radiation levels are high enough to require a several-day stay time, most occupants would not be running in and out during the first few days, and after a few days the presence of a few fallout particles in the shelter would not change the over-all dose picture to any significant degree. Nobody enjoys the gritty taste of sand in food* or the feel of it in the hair. If either food or personnel contamination by early fallout occurred there would be a natural inclination to do something about it. No special soaps or detergents or acids would be needed to remove fallout

* It is hard to visualize conditions where food would survive destruction and be contaminated and eaten in the first week or so postattack or how people could gather fresh fruits or vegetables in a heavily contaminated area. On a short-term basis, eating highly contaminated foods does not appear to be very likely and would not occur if the shelter food stocks were used during this period. The long-term problems of food contamination may be important.

particles. Brushing is an effective removal method, although washing with or without soap might help.

Visualizing the fallout as being like sand is useful conceptually in considering what might become contaminated in the first place. A hat would keep it out of the hair; any covering would keep it out of food; and even uncovered food inside an intact, closed building would not become contaminated.

Chemical Properties of Fallout

Solubility is the chemical characteristic of fallout of most concern to civil defense. Solubility influences: (1) how much of the individual radioactive elements of the fallout would be dissolved in the reservoir of a city water supply, (2) how much would be biologically available to be taken up through the root system into the edible part of a plant, and (3) how much of the radioactivity would remain behind after a contaminated street has been flushed free of fallout particles by water hosing.

Research is still under way to get better answers to these questions, but the following is known. Very little of the radioactivity would remain after the particulate matter has been removed from a contaminated area such as a parking lot or a street, so little in fact that for most practical purposes it could be ignored. Only a relatively small percent of the

total radioactive material in fallout would be dissolved in a water reservoir, and because of the dilution that would occur in most water systems, the concentration of radioactive material would be small. Thus, the hazard from drinking water that might be contaminated would be minor compared to the hazard of external exposure and, in an emergency, people needing water should not be denied it on the basis that it might be contaminated. The amount of radioactive material that could become incorporated into the edible parts of food crops also is small, and as in the case of water, hungry people should not be denied food on the basis of possible contamination. Dry foods, of course, should be washed or wiped clean if they are seen to be contaminated.

Therefore, in terms of the over-all impact of a nuclear attack, problems of protecting against food and water contamination in the early post-attack period are probably minor compared to the problem of providing protection against bacterial contamination which could result from disruption of essential services such as gas and electricity necessary for the preservation and preparation of food in our society. Even this problem would be secondary to the hazard of the external exposure to gamma radiation. Though food and water problems should not be ignored, it would be when the postattack society is attempting to return to the types of peace-time standards such as those recommended by the National

Committee on Radiation Protection and Measurements that food and water contamination control would become very important relative to the other consequences of the war. *

Radiological Properties of Fallout

Danger from fallout is due to the radiation that it emits, not to the physical or chemical properties. The fallout particles may be thought of as tiny X-ray machines or flashlights which give off radiation. The radiation from X-ray machines (X rays) can be dangerous. The radiation from flashlights (light) is not. While an X-ray machine or a flashlight can be turned off, the fallout radiation can not and it continues to be emitted at an ever-decreasing rate like the light from a flashlight as the battery runs down.

Nearly 200 individual radioactive elements are formed in varying amounts during a nuclear explosion. Each has its own "half-life" or time period in which its radiation rate decreases to one half the initial value. The over-all decay rate of fallout results from the combined radiation decay rates of all these elements and their radioactive daughters.

* There may be one exception -- that of radioiodine. Cattle grazing on contaminated pasture could, in some isolated cases, concentrate enough radioiodine in their milk so that it could damage the thyroids of very young children. Also, some radioiodine could enter the body through water contamination. This hazard could exist at most for only a few weeks postattack since the radioiodine disappears rapidly through radioactive decay.

The half-lives of the various radioactive elements range from a few seconds to many years, so that as time progresses after an explosion, the short-lived products decay out of the mixture, followed progressively by the longer- and longer-lived isotopes. Thus, the intensely radioactive mixture present early after an explosion gives way with the passage of months to only a few long-lived isotopes of any importance. Radioiodine mentioned earlier becomes unimportant after a few weeks, while two of the longer lived isotopes -- cesium and strontium -- lose only half of their radioactivity over a period of about 30 years.*

The fallout material produces two kinds of radiation that are of concern to civil defense: beta particles and gamma rays. The amount of alpha radiation would be insignificant.

The beta particles, identical to high-speed electrons, are not very penetrating and it is only when the fallout material is allowed to remain for some time on the skin or hair, or is ingested, that biological damage from beta radiation may result. Even then, since simple precautions are effective, the fallout beta hazard for humans is minor compared to that from the gamma radiation.

Gamma radiation from fallout is very penetrating, comparable to X-rays from a very high-voltage X-ray machine. While an X-ray

* The composite rate that the fallout radiation fields decay with time is discussed starting on page 18.

machine is a localized source of radiation, fallout material may be widely distributed, covering the roof of a building and the grounds that surround it. The amount of radiation emitted by this distributed source that would penetrate into a region where people might be located would depend on the physical characteristics of materials between the people and the distributed sources (walls and roofs of buildings). It would depend on the distances, size, and kind of the surfaces where the fallout has been deposited, and on the manner in which the fallout is deposited and retained on these surfaces. The total effect of such factors on the radiation reaching an area is called the penetration characteristic. Thus the penetration characteristics depend on how the buildings in the area are constructed, the construction materials used, and how the fallout is distributed around and on them. If all the fallout material were on the roof of a building and the radiation entered only from overhead, the penetration characteristics would differ from the case of fallout material being on the ground and radiation entered only through the side walls of the building. Therefore, it is not enough to say that a particular thickness of shielding material will produce a particular amount of protection. Reference to half-value or tenth-value layers, concepts which apply to unidirectional monochromatic radiation may be misleading if applied to fallout radiation penetration. Relatively, roof penetration is less for the same amount of shielding.

In addition to protection provided by shielding material between the fallout location and the protected location, the distance between them is important. Greater distance means greater protection.*

The two concepts, referred to as barrier shielding and geometry shielding, which relate respectively to the protection afforded by material and to that afforded by distance are useful to anyone desiring to understand problems associated with fallout protection.

In Figure 1, the protection provided by barrier shielding is illustrated. Consider a very long wall of various thicknesses of brick having evenly-deposited fallout on the ground on one side of the wall and none on the other. The amount of fallout radiation penetrating the wall depends on its thickness. One 4-in. row of bricks would allow about 40% to penetrate; a double thickness, about 20%; and a three-thickness layer, about 8%.**

* A detailed technology for evaluating fallout-radiation protection has been developed under the general guidance of a subcommittee of the National Academy of Sciences and forms the basis for the National Fallout Shelter Survey. The general theory of structure shielding is given in Reference 4, and engineering applications of it in References 5 and 6. The intricacies of this shielding technology are beyond the scope of this document. Office of Civil Defense publications are available in which this material is covered in detail. Also, formal instruction in the application of the shielding technology is available through a number of Universities throughout the country. These short courses, presented under OCD sponsorship, are intended primarily for architects and engineers but are open to others with the proper technical background.

** If the fallout were on the roof and the radiation penetration were through the roof, the corresponding percentage figures would be about 10% for a 4-in. thickness of brick; 5% for 8 inches; and 1.5% for 12 inches.

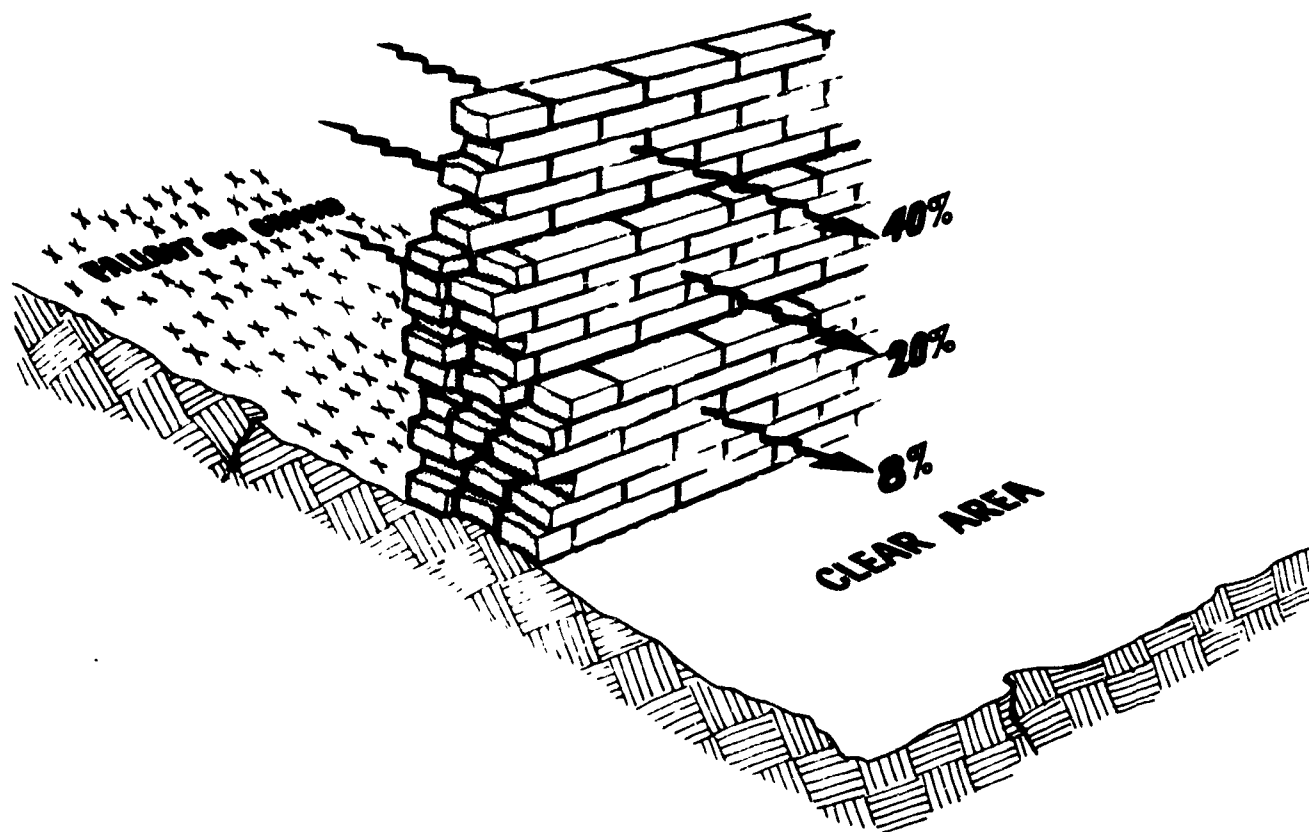


Fig. 1 - FALLOUT RADIATION PENETRATION

Figure 2 shows the effect of distance on dose reduction. If a person were standing in the center of a large, evenly-contaminated plane (illustrated by a large, smooth ice skating rink) about 50% of the fallout radiation reaching him would come from the area included within the first circle, an additional 20% from the area between the first and second circle, and the next 20% from the area between the second and the third circle; i. e., 50% from within 50 ft, 70% from within 150 ft, 90% from within 500 ft. The remaining 10% comes from beyond 500 ft. Figure 2 refers to an idealized situation, i. e., a smooth surface having infinite dimensions. A real surface, such as the asphalt or concrete of a street or the surface of a lawn, has some degree of roughness, therefore, the gamma radiation from fallout on real surfaces would be partially shielded and the distances would not be so great. Half of the radiation would come from a circular area with a radius closer to 25* than 50 ft surrounding the point of interest.

Figure 2 is also useful for conceptualizing the value of decontamination operations. By decontaminating a circular area of 50 ft radius

* In experimental programs at the Naval Radiological Defense Laboratory and at the Army Nuclear Defense Laboratory, values as low as 10 ft have been observed. Additional experiments are being scheduled to get better data on ground-roughness effects. It should be noted that the reduction of fallout contribution with distance due to ground roughness is more pronounced near the surface; the effect goes down with altitude.

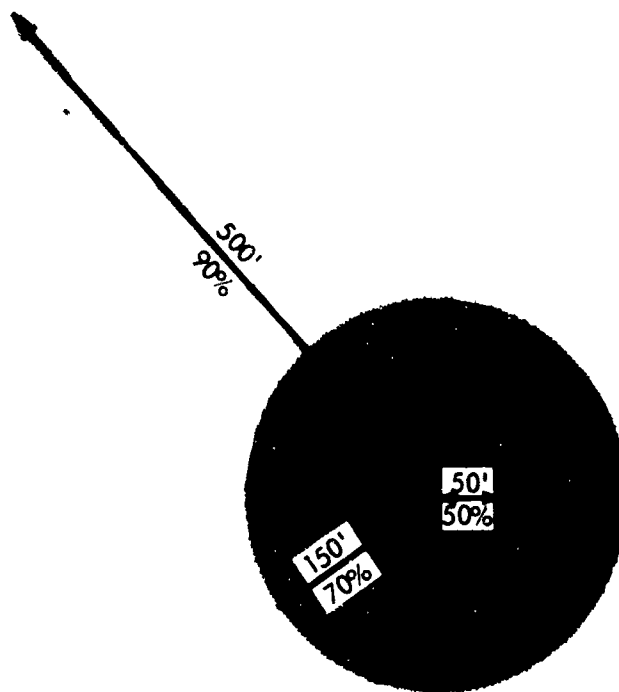


Fig. 2 - DOSE CONTRIBUTION vs DISTANCE

(more like 25 ft in the real case), the dose rate at the center of the area can be cut in half. Since a person normally does not stay at one place, and more than one person usually is involved, generally larger areas must be decontaminated; but even so, the size of the areas to be decontaminated to reduce radiation to a particular location need not be excessive.

Standard Intensity and Radiation Decay

The radiation level from any given quantity of any radioactive material reduces with time. The reduction with time for a particular quantity of fallout would depend on such things as the design of the weapon or weapons that produced it, the altitude of detonation, the type of material in the environment at the place of detonation, the amount of fractionation,* and whether or not the fallout were from two or more weapons detonated some time apart. None of these things could be sufficiently well known in time to be of much use to the civil defense official during an attack or in the early time period following it. However, an

* The exact composition of the radioactive material in fallout will vary depending on such things as its time-temperature history in the fireball. This means that fallout deposited close-in very early after the burst would have different relationships among the amounts of the individual radioactive elements than would the fallout occurring later some distance away. See Reference 2 for a detailed discussion.

easy-to-use approximation of the rate of radiation reduction may be obtained by assuming that radioactivity is related to time after the burst that produced it raised to the negative 1.2 power ($t^{-1.2}$). * Since $7^{1.2}$ is about 10, this leads to the familiar 7-10 rule-of-thumb, i.e., for each 7-fold increase in time post-detonation, there is a 10-fold reduction in radiation level.

It is well known that this approximation is imperfect but it provides a tool useful for planning. Errors could be large in the early time periods following deposition of fallout from two or more weapons detonated some time apart or if the fallout were produced by a so-called "clean" bomb. **

It must be kept in mind, however, that this or any other decay relationship refers to the behavior of the radioactive material and does not refer to the intensity of gamma radiation at a particular place unless the radioactive material has been there and is undisturbed during the time being considered. For example: the $t^{-1.2}$ function (or 7-10 rule-of-thumb) must not be applied in a particular location until fallout is all down. Assume that fallout commenced at say 3 hours post-detonation

* See Reference 1, starting with Section 9.12.

** A nuclear weapon is termed "clean" if the energy from fissionable material (uranium or plutonium) is a small percentage of the total. On the other hand, it is termed "dirty" if most of the yield comes from "fission." A "normal" weapon is about 50% fission.

and was not completed until say 3 hours later. Although the radiation level would be measureable during the time of deposition (3 hr to 6 hr), attempts to calculate future radiation levels if these measurements were mistakenly used to determine the standard intensity (see below) might lead to serious error, and this error would not be in the direction of safety. Also, if rain or wind should cause redistribution of the fallout, this relationship would not hold.

After deposition is completed, a calculation based on a series of measurements can indicate what the level (usually at 3 ft above the ground) would have been at one hour after the detonation that produced it, if the deposition had been completed before that time. The number resulting from this calculation is referred to as the Standard Intensity (SI).

Therefore, for general planning purposes, total exposures and future radiation levels may be estimated by use of the formula:

$$R/hr * SI t^{-1.2} **$$

where:

(R/hr) is the radiation level at (t),

(SI) is the standard intensity (R/hr), and

(t) is time in hours measured from the time of detonation.

* Most readers of this document probably are familiar with the unit Roentgen (R) which is used as a measure of radiation exposure (dose). Roentgens per hour (R/hr) is used as the unit of exposure rate (dose rate or radiation level). An explanation of these units may be found in Reference 8. More rigorous definition of these and other units of radiation measurement may be found in other handbooks of the National Committee on Radiation Protection and Measurements.

** A choice of other fallout radiation decay curves or relationships may be necessitated for different assumptions about any of the factors that influence the decay, but usually this would represent a higher level of sophistication than is necessary for a general understanding of post-attack exposure control problems.

Numerous nomograms, charts, and slide rules are available for this calculation.

OPERATIONAL EFFECTIVENESS CRITERIA

In considering the potential benefit of some fallout countermeasure such as shelter or decontamination, it seems natural to use as an index of merit the ratio of the radiation level expected without the countermeasure compared to the level expected with it, i.e., what happens if nothing is done compared to what happens when improvement efforts are tried? For example, if one expected decontamination to reduce a potential radiation level from 25 R/hr to 5 R/hr, the index of merit (measure of performance) would be $25/5$ or 5. Similarly in the case of shelter, the expected radiation level in-shelter divided by the level without any shelter would seem to be a reasonable basis for evaluating shelter quality, but for shelters, there is no practical basis for evaluating the "without shelter case." There is always something in the environment -- ground roughness, buildings, lakes or rivers -- to provide some reduction in the radiation level (protection). This would apply even for the persons standing in the middle of a large parking lot.

To circumvent this problem, a standard "without shelter case" has been defined. This is but one difference that exists between the index

of merit that describes the potential benefit of a fallout countermeasure such as shelter, and the index of merit that describes the potential benefit of a fallout countermeasure such as decontamination. Although both indices are ratios, there are important differences in the way they are formed and applied operationally. In examining shelters and decontamination actions and their effectiveness, it is important to realize they are not competing systems to be evaluated against one another. On the contrary, they are complementary systems whose total effectiveness depends on their combined usage.

Protection Factor (Pf)

"Protection factor" (Pf), the index of merit for a shelter is defined as the expected radiation level in the location of interest (shelter) compared to the level that would exist 3 ft above a smooth, infinite plane contaminated with the same amount of fallout per unit area. Thus, the unsheltered case is hypothetical and it never did nor could exist in a real situation. This Protection factor was defined by Dr. L.V. Spencer of the National Bureau of Standards* who was responsible for much of the basic theoretical work that lead to the development of a fallout shielding technology used throughout civil defense. Protection factor, having

* See Reference 4, Section 18 on page 10.

this meaning, is used in all National Fallout Shelter Survey data and is used in the technical material on fallout shielding analysis and in the radiation shielding courses for architects and engineers.

Furthermore, such a definition is necessary for studying effects of hypothetical attacks. The theoretical fallout patterns laid down by a computer also must standardize to some stated condition and the hypothetical smooth plane, which is the only truly unambiguous condition, is a logical choice. So Pf, as it is used in civil defense planning, is not simply the ratio of the expected outside-inside radiation levels and to consider it as such may lead to appreciable error.

The analytical technique used to determine the Pf of a particular shelter location also can be used to determine the Pf outside.* In effect, it is assumed there is a house in the outside location of interest having zero ceiling height and zero thickness walls. In a number of such analyses performed recently, typical outside Pf's were found to be about 1.5.**

* A rigorous restatement of this sentence without referring to Protection factor (Pf) and underlining its replacement is: "The analytical techniques used to determine the ratio of the radiation level that would occur 3 ft above a very large surface of ideal smoothness to the level that would occur with the same amount of fallout in a particular shelter location can also be used to determine the ratio of the radiation level that would occur 3 ft above a very large surface of ideal smoothness compared to the radiation level that would occur with the same amount of fallout measured 3 ft above the ground outside."

** See Reference 7 for the detailed calculations, pictures, and diagrams relating to the situations analyzed.

Thus, if the Pf in the shelter location were calculated and reported as say 100, the outside to inside radiation level expected would be $\frac{100}{1.5}$ or 67. If the outside Pf's had been calculated for a location quite close to the buildings, their values might have doubled, thus reducing the expected ratio of outside to inside radiation by about another factor of 2 becoming 3 rather than 1.5. So in these cases, buildings with Pf's of 100 might have outside to inside ratios of radiation level of perhaps 35 rather than 100 as might have been assumed on the basis of misinterpretation of the meaning of Pf values assigned by the National Fallout Shelter Survey (NFSS).

The association of a "Protection factor" with a location provides a useful tool for planning shelter utilization, assessment of damage from a hypothetical attack -- in general for the planning that must be done preattack, including the formulation of hypothetical decontamination problems to provide practice in decontamination problem solving.

Events that are to take place postattack should be planned and performed using real data that then would be available. Use of the pre-calculated idealized protection factors may lead to serious error. There would be no need for a hypothetical, smooth plane of infinite dimensions as a reference. Because of variations in the fallout pattern, it would be quite conceivable that the radiation level would be higher in

another shelter location not too far away having even a higher Pf. Instruments would provide real information about the radiation hazard in the shelter and outside or other places of interest. The problem facing the Civil Defense Director, or the Shelter Manager, if the radiological situation became critical is not to find a location with a better Pf but to find a place where the radiation hazard is less, or to determine if there is anything else that would reduce the expected radiation exposures.

Thus, NFSS Pf's would not be very helpful for postattack operations since they could not take into account: the actual deposition patterns of the fallout; the subsequent redistribution through weathering or gravity (i. e., fallout sliding off the roofs); decontamination; changes in the penetration characteristics of the radiation; or effects due to blast and/or thermal radiation from the explosions.

Countermeasure Factor (Cf)

Somewhat analogous to Pf, which relates to shelters, a term is needed for describing the effectiveness of radiation exposure reduction countermeasures applied during the post-shelter period. For purposes of standardization, the term Countermeasure factor (Cf) is suggested. Cf may be defined as the number obtained by dividing the radiation level at the point of interest after the countermeasure is applied into what the

level at the same point and at the same time would have been without it. Thus, C_f like P_f is a number larger than 1 and like P_f , C_f could vary from one point to another even in the same shelter area, but it is not standardized by reference to the hypothetical, infinite, smooth plane as the P_f is.

Decontamination of a large parking lot outside a building might produce a C_f in an area in the building quite near the lot of say 1.5, whereas the same action would produce a C_f of only 1.1 in a section of the building further away from the lot. The C_f resulting from the decontamination of the parking lot in the lot itself might be as much as 20.

C_f 's may be estimated preattack for particular locations for various possible post-shelter countermeasure actions and thus provide guidance for postattack use.* As an example, assume that postattack it is determined that the radiation level in a particular food-processing plant must be reduced to one half if the plant is to be used at a particular time. C_f 's in the plant, previously estimated to result from the various possible

* For making such estimations, it generally may be assumed the gamma radiation from fallout in the early post-shelter period will have an energy spectrum and penetrability approximating that of early fission products, i. e., the assumptions about the fallout gamma energy and angular distribution used in the National Fallout Shelter Survey will apply for radiation protection and dose calculations applicable to decontamination or evacuation through a contaminated area. (See Reference 4.)

decontamination actions available (i.e., roof, parking lot, nearby roofs), or improvised shielding (such as sand-bagging windows) would provide useful guidance as to whether it would be possible to reduce the radiation level this much and how best to go about it. Pre-attack planning and the exercising of the plan (assuming various fallout radiation levels, fallout distribution, etc.) would be useful. Such planning and decontamination exercises would no doubt increase the likelihood that postattack operations would be efficient and successful. Even if the decontamination requirement cannot be firmly established pre-attack, the planning should be so thorough and flexible that the required decontamination could quickly and efficiently be performed as needed.

Radiation Exposure Criteria

In the final analysis, the criteria for the assessment of the effectiveness of a post-shelter radiological countermeasure is first how many people it saves, and second how many it keeps from getting radiation sickness. Always, decontamination or any other exposure control countermeasure should be used wherever practicable to reduce exposures, but the final measure of effectiveness is the number of people, who because of it, do not become radiation casualties. This is consistent with the criterion for evaluating the effectiveness of various possible

shelter programs including the current National Fallout Shelter Program of OCD.

The questions of the relationship between exposures and effects and how much exposure should be accepted under what circumstances are very difficult to answer.

The statement that unnecessary exposure should be avoided always is not likely to be debated by anyone, but it is not very useful to a civil defense official who also wants to keep the people for whom he is responsible as comfortable and as well fed as he can, and who wants to get them out of shelters to start recovery. How does he compare the consequences of additional exposure to the advantages of leaving shelter?

To provide this kind of guidance, the National Committee on Radiation Protection and Measurements issued Handbook No. 29, "EXPOSURE TO RADIATION IN AN EMERGENCY." In this handbook, the concept of ERD* (Equivalent Residual Dose) is developed. The important feature of this concept is recognition of the fact that recovery from radiation

* The concept of ERD is discussed in detail in Appendix II of Reference 8. The ERD refers only to those short-term radiation effects, i.e., the radiation sickness or death that would occur within weeks to months post-attack and not the longer-term effects such as shortened life expectancy or increase in probability of biological malignancies that might manifest themselves many years later. Also, it is assumed people are in "average" good health and are not suffering from other injuries such as fractures, hemorrhage or burns.

injury occurs over some period of time after the onset of exposure.

Since recovery is a continuous process, the effect of a few hundred roentgens received over a period of several months will be quite different from the effect of the same exposure delivered in a few minutes or days. In simple terms, recovery is equivalent to subtraction of some number of roentgens from the total radiation exposure up to a particular time.

The ERD is computed on the assumption that 10% of any radiation damage is irreparable with the remaining repairable part repaired at the rate of 2.5% per day. The Handbook assumes that no repair occurs during the first 4 days, but this assumption may be ignored in ERD computations because its effect is so small. According to Handbook 29, most people are expected to be able to take care of themselves if their ERD's remain below about 200 roentgens.

In addition to the contribution to reducing the exposure of the general population, decontamination also will be employed to allow earlier access to important facilities denied because of high radiation levels. When should this decontamination be undertaken?

In a post-attack environment, the resumption of activities in vital facilities and industries must be scheduled so that the radiation exposures to the personnel engaged in the activities remain below some

acceptable amount. Thus, when the radiation level in a region where an activity must take place is sufficiently high, the activity is prohibited and, in such situations, it is necessary to wait for the radiation level to decrease. The time of postponement is called the denial time and the denial time decreases as radiation level decreases. Therefore, because decontamination can effectively decrease the radiation level in a region by a factor C_f , decontamination can effectively decrease the denial time associated with the recovery of an activity. A recent analysis* indicates that reducing the radiation level by a factor of 10 causes the denial time to be reduced by a factor ranging from 7 to 20 and in most cases by a factor greater than 10, and unless the denial time without decontamination would be greater than about 3 months, the denial time can be reduced by decontamination to less than nine days. This reduction in denial time is time saved in preparing an activity or facility for recovery and, therefore, the mark of quality becomes "time saved."

Translation of "time saved" into some value unit relating to "people saved," or to earlier recovery of the economy, or to restoration of the United States as a dominant world power may be very complex and no attempt is made to do so here. (For example, it would be difficult now -- preattack -- to estimate the number of people who would be

* See Reference 7.

saved or the net reduction in suffering if a certain pharmaceutical plant were started up say 1 month postattack compared to 3 months. In a postattack situation, such requirements might be quite self evident.)

METHODS OF POST-SHELTER EXPOSURE CONTROL

There are 3 possible ways for reducing the exposures of people in any particular contaminated area: (1) shielding against radiation (shelter), (2) removing the contamination (decontamination), and (3) removing the people (evacuation). In a real situation, combinations of these would be used, but to facilitate understanding of their potential contributions and their relationships, they are discussed separately. Requirements for exposure reduction measures in various assumed postattack situations are given in the Section entitled "ILLUSTRATIONS."

Partial Use of Shelters

In the post-shelter period, * nominally defined as being a maximum of 14 days after fallout occurs, continued part-time use of the shelter may be desirable to prevent the radiation exposures of the shelterees

* The shelter period is considered to be the shelter time during which essentially full-time occupancy is necessary and excursions outside the shelter of more than a few minutes duration would result in substantial additional exposure.

from becoming excessive. In fallout areas where the Protection factors of the shelters are adequate to keep people who remained in the shelter from getting a radiation sickness dose (potential 200 R ERD) in the first two weeks, only part-time use of the shelter would be required after the two weeks to keep the ERD from increasing.* (The amount of time that must be spent in the shelter will vary. See "ILLUSTRATIONS," page 40.) This assumes that the fallout occurs from a single weapon, or weapons, detonated no more than a few hours apart, and that the people having access to shelters get to them and use them properly.

There are important implications:

1. By the end of the shelter period (2 weeks), the body is repairing the radiation injury faster than it is being accumulated.
2. Those who get radiation sickness will have received the doses responsible for the sickness before the end of the shelter stay-time, the major part of the dose considerably before the end of the second week. Although early nausea may occur, it probably would not last long and the serious illness may not manifest itself until some time later. Normally there is a few days to a week or so latent period between the exposure and the onset of the illness it produces.**

* See References 7, 9, and 10.

** See Reference 1, starting with Section 11.115.

3. A shelter must have had adequate Pf if people survived within it for two weeks without showing evidence of having received a sickness dose. People might not have enough food or water for continued occupancy but unless something happens to the building -- such as destruction by fire -- a more than adequate physical capability for continued control of radiation exposure still exists. ("More than adequate" refers only to the criterion of keeping people from becoming radiation casualties.)

This means that in any shelter situation, subject to the assumptions given, full-time occupancy of the shelter should not be necessary after two weeks. In most cases, the time period may be considerably less than two weeks. The amount of time permitted outside of the shelter will depend on many things including the protection available outside, the amount of decontamination, the standard intensity, and the Pf of the shelter, but in any case the out-of-shelter times would be significant, varying from short times such as might be required for food and water reconnaissance trips to longer times such as a full-work shift.

Decontamination

Many hypothetical attacks show large sections of the country covered with high levels of fallout. The purpose of decontamination is to achieve a reduction in the radiation level at some place or places of interest. This reduction is achieved by relocating or covering the fallout material. Most of the fallout material eventually must be removed from roofs and city streets but generally only small selected areas need high-priority attention for the purpose of radiation exposure control in the sense discussed here.

Early decontamination and later clean-up operations would have some things in common, but there would be differences. For early decontamination, operating time is very important because of equipment availability limitations and the importance of limiting crew exposures. Disposal of the contaminant is of considerable concern because of its continuing radioactivity. The later clean-up operation would have characteristics similar to longer-term recovery operations such as general debris removal, and could be undertaken in a more normal way.

Decontamination should not be considered as a substitute for inadequate shelter. In general, it should not be considered a countermeasure to be applied during the early period (up to a few days) postattack.

Decontamination basically is a recovery countermeasure. Its use

allows earlier emergence from shelter and earlier availability and utilization of important survival resources, such as water and food-distribution and processing facilities, and important industries.

Decontamination should be undertaken when it has been determined that such action is required to achieve a goal important to recovery and then the decontamination problem has to be evaluated in the context of actual circumstances that exist. For example, recovery of a food-processing plant may be desirable, but in planning the recovery, questions about the need for food and the availability of a labor force must be considered including the radiation exposures already received by the plant personnel and the amount to be received during off-duty time and enroute to and from work.

To illustrate: There may be several reasons that a parking lot near a food plant would be a desirable place to initiate decontamination. Parking lots usually are not difficult to decontaminate and, therefore, may provide a staging area for additional work; and the parking lot may merit decontamination to reduce the exposure to personnel enroute to and from work.

The central feature of the current National Civil Defense Program is a fallout shelter system based on the inherent protection identified in existing buildings and incorporated in certain new construction. This

protection resource is to be augmented by additional shelter spaces resulting from the shelter development program which has been presented to the Congress. Shelter spaces having protection factors of 40 and above are included in the current National Fallout Shelter Program. The decontamination countermeasure should be consistent with and should support the shelter countermeasure.

Plans to decontaminate should be based largely on existing resources. Normal or easily-modified standard equipment should be used. These include street sweepers and flushers, fire-fighting equipment, road graders and dump trucks, and in so far as possible, the plan should depend on the services of personnel who normally operate the equipment. There are important differences between the ways equipment would be used for decontamination and the ways they are normally used which should be taught to the equipment operators, as should the methods for minimizing radiation exposures.

Decontamination operational plans should avoid elaborate techniques and requirements for complicated and highly-specialized training for decontamination analysis. Rudiments of shielding analysis and of radiological monitoring techniques would be useful and a trained RaDef officer or graduate of the Shielding Analysis course would seem to be a good potential training candidate for decontamination training.

Removal of Fallout Material

The amount and weight of material associated with any level of "Standard Intensity" (see page 18) will vary depending on several factors including weapon design, meteorological conditions, and fractionation.* The method now generally used** for estimating the mass of particulate material for any given fallout situation takes these variables into account. Both theory and experience from weapons-test programs show that the mass of material associated with an amount of fallout which would be of concern in an emergency situation is not insignificant. Unlike the radiation they would emit, fallout particles could be seen; they could be tasted; they could be felt; they might even have an odor depending on the characteristic of the terrain or other material over which the bomb that produced the fallout was detonated.

Decontamination is primarily a physical process, not a chemical one. It is more comparable to removing snow or dirt or dust from a street than it is to the removal of varnish by a paint remover from a piece of furniture. Acids, detergents, or elaborate surgical scrub-up techniques are not required. The eye is probably the best practical gauge for measuring the effectiveness of removing the fallout material

* See footnote, page 18.

** Developed by Dr. Carl Miller. See Reference 2 for the details of the Miller Model, and Reference 3 for calculations based on it.

just as it is for determining how effective is the sweeping of the kitchen floor.

The practical implications for decontamination operations are important. If the time should come when a decontamination plan must be implemented, a quick inspection of the most obvious sources of radiation -- parking lots, streets, and roofs -- should be made. If there is no visible contamination present as might be the case where the wind or rain had removed it from a roof, or traffic had cleared it off a street, a decontamination effort for that surface is not warranted. For an area that has fallout material on it, a decision as to whether decontamination should be undertaken should not be difficult especially if the estimated value of removing the contamination toward reduction of the radiation level in the area of concern had been made beforehand. But a fairly accurate evaluation of the decontamination effectiveness requires use of an instrument.

Since decontamination involves the removal of particulate matter from one place to some other place, consideration must be given to the danger involved in concentrating this matter. Thus, locations for "fallout garbage dumps" would need to be carefully selected.

Evacuation (Remedial Movement)

Evacuation as a post-shelter exposure control method means moving people from an area highly contaminated by fallout to one with less or no contamination or moving them from a poor shelter to a better one.

In a fallout area, in general people should not be moved from a shelter location because of high radiation levels in the first few hours, or a day or so, following fallout arrival. There are two important reasons: first, they might receive excessive exposures during the movement period; and second, some time may be required to identify the location of safer areas and whether or not the areas have space available and are habitable. For these reasons, it is expected that the evacuation tactic would be used mostly during the time period of days to weeks postattack.

The time to start evacuation would depend on how far the people have to go, and the means available for transporting them.* If they were to be evacuated by foot through a contaminated area, an important dose reduction could be achieved by having them move in a close-pack formation.** For example, a group of 20 could reduce the average dose by

* In Reference 11 it is shown that the minimum time to initiate evacuation is quite critical but is followed by a broad optimum time thereafter. This subject is also discussed in Reference 12.

** The midsection is the critical part of the body subject to early effects of radiation. The head and extremities, particularly the feet, are considerably less radiosensitive. Later effects such as cataract production, of course, depend on exposure to the eyes. (This assumption is particularly pertinent to the dose reduction obtained by crowding people in a shelter or by marching them in close formation through a contaminated area.) (See Reference 13.)

about a factor of 2 below the dose they would get moving separately.

For 60 people, the average reduction could be a factor of 3.

ILLUSTRATIONS

The chart on page 41 shows the necessary countermeasure factors (Cf's)* (see page 25) for various quality fallout shelters under various fallout conditions for various effective fallout arrival times. No significance should be attached to the particular values for Pf and SI used in the chart; they were chosen because the data relating to them were readily available.

These data are based on the assumption that the stay-time in the primary fallout shelter is continuous for the first two weeks. The criterion is the radiation sickness dose (200 R ERD). There are three columns under each protection factor category representing 1-, 6-, and 24-hour effective arrival time.** The 1's mean that no post-shelter exposure control is required and the X's mean that the primary shelter protection factor is not adequate to keep the occupants from getting radiation sickness.

* In this case, Cf also includes, in addition to the radiological countermeasure, the natural inherent protection afforded by ground roughness and the protection afforded by existing structures.

** Standard Intensities as high as the values shown in the chart are not expected for fallout arrival times greater than 24 hours, and only small areas of the country would be expected to experience the high SI values shown, even after a heavy nuclear attack.

REQUIREMENTS FOR POST-SHELTER EXPOSURE LIMITATIONS*

SI k/hr	Pf											
	10			57			250			1,000		
	1**	6	24**	1	6	24	1	6	24	1	6	24
280	1	1	1	1	1	1	1	1	1	1	1	1
850	X	1	1	1	1	1	1	1	1	1	1	1
2,200	X	X	4.5	2.7	2.3	2.1	2.1	2.0	2.0	2.0	2.0	2.0
6,700	X	X	X	X	13	8.3	7.6	6.7	6.3	6.3	6.3	6.3
14,300	X	X	X	X	X	50	20	16	15	14	14	13
28,600	X	X	X	X	X	X	X	47	35	31	29	28
57,200	X	X	X	X	X	X	X	X	X	83	67	59

The 1's mean no postshelter exposure countermeasure is required.

The X's mean shelter Pf's were inadequate to avoid radiation sickness.

The other numbers indicate the degree of post-shelter exposure control in units of Countermeasure factor (Cf) required to keep the total radiation exposure, during shelter and after, below the sickness level.

* This chart is based on material contained in References 7 and 10.

** 1, 6, and 24 are the effective fallout arrival times in hours.

In none of the shelter cases considered for the standard intensities of 280 R/hr would post-shelter control be required. For the standard intensities starting with 850 R/hr 1-hr arrival time, in the area of the chart represented by the X's (lower left triangle), the shelters would be inadequate to keep their occupants from becoming sick. The problem, therefore, would not be one of post-shelter exposure control, but a problem that must be solved before or during the shelter period by such things as improvised shelter Pf improvements. Decontamination or evacuation countermeasures probably would be too late to do much good.

Cf numbers in the chart, in most cases, are not high, i.e., readily achievable, and in all cases the Cf's are less than the shelter Pf's. This means that the requirement for post-shelter radiation protection always could be met by continued part-time use of the shelter. If decontamination is chosen as the preferred or auxiliary exposure-reduction measure, the level of decontamination effort required is not likely to be excessive. In Reference 7, a number of decontamination problems were studied in detail. Real buildings in real areas, selected from the NFSS data were analyzed. Decontamination effectiveness greater than that shown to be required by the chart usually was calculated to be readily achievable without excessive cost in labor, time, equipment, or crew exposures.

The evacuation tactic might be chosen depending on such things as evacuation distance and availability of transportation as discussed on page 39, and in References 10, 11, 12 and 13. Advantage can be taken of mutual shielding of the evacuees.

By the end of the two-week period, the standard intensities would have reduced to about 1,000th of the values shown on the chart. The actual outside readings would be lower than this by perhaps another factor of 2 because of the ground roughness and mutual shielding provided by buildings.

The two-week shelter stay-time was used since it is the nominal period for which shelters in the NFSS are being stocked. In a real case, the required shelter stay-times frequently would be much less than two weeks, or the evacuation or decontamination tactic might be used before the end of the two-week period. Also, in a real situation, certain of the exposure-reduction methods might be used so as to keep the ERD considerably below the sickness dose.

The meaning of the values of Cf given in the chart may be clearer if used in examples. Refer to the box in the chart at the intersection of the row where SI is 14,300 R/hr and the column of one hour effective arrival time for a shelter Pf of 1,000. An arrow indicates the Cf of the box, 14. Assume answers to two questions are needed.

1. How much time could be spent outside the shelter at the end of two weeks assuming continuous shelter stay period and no decontamination, if the average Cf over the day is to be kept to 14?

2. What would be the decontamination requirements in a nearby work area having the same SI (14,300 R/hr), if 8 hours were to be spent at work and 16 hours in the shelter, and the average Cf for the day kept at 14?

For Question 1:

Let T be the number of hours spent out of shelter and assume the average radiation level outside is reduced from the theoretical value by ground roughness and the shielding influence of nearby buildings to 67% making the effective Cf outside the shelter $1/.67$ or 1.5.

Then:

$$\frac{24 - T}{1000} + \frac{T}{1.5} = \frac{24}{14}$$

Solving for T, the answer is about 2.5 hours per day outside shelter.

For Question 2:

$$\frac{16}{1000} + \frac{8}{Cf} = \frac{24}{14}$$

Solving for Cf, the answer is that decontamination must achieve a Cf of 4.6.

In most cases this number could be readily achieved through decontamination. *

The basic purpose of the chart is to show that it is technically feasible to keep post-shelter radiation exposures below the level that would make people sick. That is: If the shelter system serves its function of keeping people alive and if the shelterees do not become sick from the radiation doses they get during their shelter stay period, there is no basic reason why they should become sick from the doses they receive afterward.

* Volume 11 of Reference 2 discusses the problems and procedures of radiological target analysis in detail. Relationships between radiation levels and exposures for combinations of countermeasures are explained. This also is discussed in a very recent report, Reference 9.

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